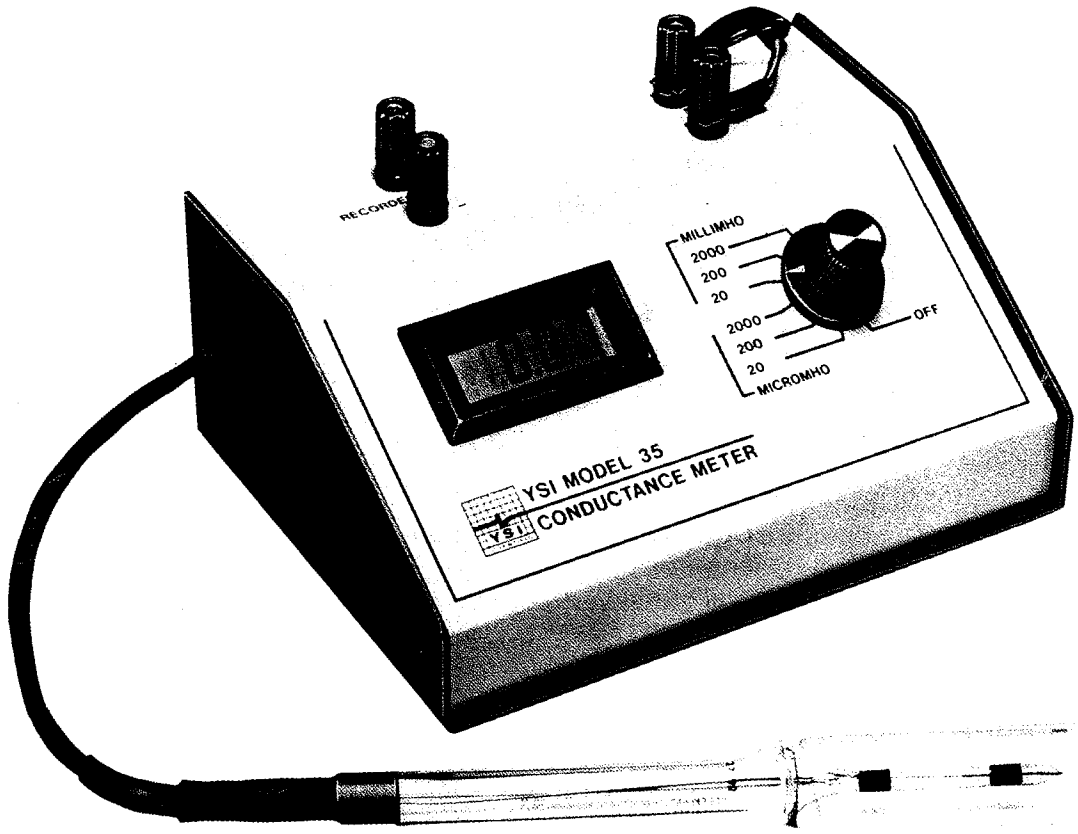


YSI MODEL 35 CONDUCTANCE METER INSTRUCTION MANUAL



YSI Incorporated

Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio 45387 USA
Phone 513 767-7241 • 800 343-HELP • Fax 513 767-9353 • Telex 205437

PRICE \$10.00

TABLE OF CONTENTS

| | PAGE |
|---|------|
| GENERAL DESCRIPTION | 1 |
| Principles of Operation | 1 |
| SPECIFICATIONS | 2 |
| CONDUCTIVITY CELLS | |
| Description | 2 |
| Cell Constant | 3 |
| MEASUREMENT PROCEDURE | |
| Instrument | 4 |
| Cell Precautions | 4 |
| Temperature Correction | 5 |
| Small Sample Measurement | 6 |
| MAINTENANCE AND CALIBRATION OF CELLS | 7 |
| Cleaning and Storage | 7 |
| Platinum Block Inspection | 7 |
| Replatinization | 7 |
| Calibration and Standard Solutions | 7 |
| APPENDICES | 9 |
| I. Temperature Correction Data for Typical Solutions . . . | 9 |
| Circuit Description | 9 |
| Instrument Calibration | 10 |
| Troubleshooting and Repair | 11 |
| Troubleshooting Tables | 11 |
| Service Parts | 12 |
| Schematic Diagram and Component Layout | 13 |
| II. Temperature Correction Data for Typical Solutions | 15 |
| III. Conductivity System Accuracy Considerations | 16 |
| IV. Warranty | 18 |

GENERAL DESCRIPTION

The YSI Model 35 is a precision laboratory instrument that presents measured conductance values on a digital display. Speed and reproducibility of measurement are enhanced because the necessity of manually balancing a bridge circuit has been eliminated. The circuit also accommodates a wide range of conductivity cell electrode-to-solution capacitance values with no need for a separate compensating capacitor.

In addition to the digital display, an analog output is provided at top panel binding posts for external recording of conductance. This feature allows the instrument to be used for monitoring, controlling, data-logging, and in such applications as conductometric titration for which a continuous record is desired.

Principles of Operation

Conductivity is determined by measuring the conductance, which is the ratio of current to voltage, of a conductivity cell immersed in the solution of interest. A cell constant then relates the conductivity of the solution to the conductance present at the cell terminals. The Model 35 will display conductivity directly, in sub-multiples of mhos/cm, when used with any cell having a constant of 1.0/cm. Cells with other constants will produce different results as may be desirable for certain applications (see Cell Selection).

Fundamentals

In S.I. units, 1 siemens equals 1 mho, but the dimensions of the cell constant must also be considered when converting observed conductance to conductivity. It has been an unfortunate but common practice to drop the dimensional unit when expressing cell constants. For example, in U.S. practice (cgs metric) we refer to a cell constant of 1.0 when we mean $K = 1.0/\text{cm}$. In the S.I. system (mks metric) a cell constant of 1.0 means $1.0/\text{m}$, which is equal to $0.01/\text{cm}$ in cgs units.

The standard measure of electrolytic conductivity is specific conductance; its unit has no name, but is usually expressed by the letter k and defined as the reciprocal of the resistance in ohms of a 1 cm cube of liquid at a specified temperature. The units of specific conductance are siemens/meter (mks) or mhos/cm (cgs) (siemens/meter = mhos/100 cm).

The observed conductance ($\frac{1}{R}$) of a solution depends inversely on the distance between the electrodes, d , and directly upon their area A :

$$\frac{1}{R} = k \frac{A}{d}$$

For a given cell with fixed electrodes, the ratio d/A is a constant called the cell constant K . Therefore:

$$k = \frac{K}{R}$$

Conductivity is determined by multiplying the measured solution conductance by the cell constant K (being careful to observe the dimensions of the constant).

For an observed conductance of 100 micromhos (or 100 microsiemens) and a cell constant of 0.1/cm

$$k = 100 \mu\Omega^{-1} \times 0.1/\text{cm} = 10 \mu\Omega^{-1}/\text{cm}^*$$

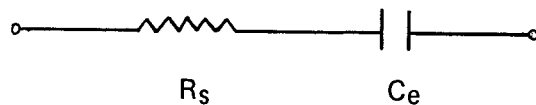
In S.I. units, the cell constant $K = 0.1/\text{cm}$ would become $K = 10/\text{m}$ and the *same* conductivity is expressed:

$$k = 100 \mu\text{S} \times 10/\text{m} = 1 \text{ millisiemens}/\text{m}$$

Instrument Method

The Model 35 obtains a conductance reading by varying the amplitude of a square-wave current forced through the cell so that the time-averaged magnitude of the cell voltage over each half-cycle is constant and is equal to a reference voltage. In this condition, the current and the conductance are directly proportional.

The forced current method minimizes the error in measurement, from series capacitance at the conductivity cell, introduced by electrode polarization effects. This may be understood by considering a simplified model of the cell-solution system which consists of a capacitor, C_e , in series with the solution resistance R_s :



During the first half cycle of cell drive, a current of fixed magnitude is forced through the cell. The resulting voltage across the cell then consists of two components: a step voltage across the resistance, and a linear ramp with positive slope across the capacitor.

When the second half cycle of cell drive starts, the current is abruptly switched to flow in the opposite direction with the same magnitude. Here again the voltage across the cell may be considered to be the sum of two components: a step voltage of opposite polarity as before across the resistance, and a linear ramp with negative slope across the capacitor. When

* $1 \text{ mho} = \frac{1}{\text{ohm}} = \frac{1}{\Omega} = \Omega^{-1}$

the complete cycle of cell voltage is demodulated and filtered, the components due to charging and discharging the capacitor cancel, leaving a voltage proportional to R_s independent of C_e .

This model is greatly simplified and there are some practical limitations to the method, but reductions in capacitance effect of an order of magnitude, as compared to classical bridge circuits, are readily achieved.

Full-wave synchronous demodulation practically eliminates meter sensitivity to drive frequency varia-

tions, while shortening response time and rejecting most external interference sources.

Series resistance introduced at the binding post terminals and in the cell cable, adds error in all two-wire conductance measurements. The magnitude of this error is normally negligible because the high conductance of the connecting wires and terminals has little effect on the low conductance of most solutions. This is not the case for concentrated acids where the conductivity may approach one mho/cm.

SPECIFICATIONS

Accuracy

Accuracy \pm (% Full Scale)

| Display Range* | Maximum Reading | Resolution | 0 to 15 & 30 to 45°C | |
|------------------|-----------------|---------------|----------------------|--------------------|
| | | | 15 to 30°C Ambient | 30 to 45°C Ambient |
| 0-20.00 micromho | 19.99 | 0.01 micromho | 0.25 | 0.6 |
| 0-200.0 micromho | 199.9 | 0.1 micromho | 0.25 | 0.6 |
| 0-2000 micromho | 1999 | 1 micromho | 0.25 | 0.6 |
| 0-20.00 millimho | 19.99 | 0.01 millimho | 0.25 | 0.6 |
| 0-200.0 millimho | 199.9 | 0.1 millimho | 0.25 | 0.6 |
| 0-2000 millimho | 1999 | 1 millimho | 1.00 | 2.0 |

*Effective measurement range restricted by accuracy considerations.

Cell accuracy must also be considered when converting conductance to conductivity values.

Conductivity Cells: Use with any YSI 3400 Series Conductivity Cell.

Recorder Output: 0 to 2.0 volts proportional to display.

Load Resistance: Not less than 10k ohms

Linearity: linear to 50% over-range (3 volts)

Settling Time: Typically 5 seconds or less to within 2 counts of final reading up to 200 mmho, and 10 seconds or less to 2000 mmho

Power Requirements: 115 VAC \pm 10%, 60 Hz, 0.10 amperes RMS maximum

Ambient Temperature Range: 0 to 45°C

Storage Temperature Range: -10 to 60°C

Size: 11 x 20 x 15 cm (4-1/4 x 7-3/4 x 5-3/4 in., 2-1/4 lbs.)

Compliance with FCC emanation rules (47CFR Part 15 Subpart J), as applicable, has been verified on this product design for Class A and Class B environments.

CONDUCTIVITY CELLS

Description

YSI offers several standard dip and flow-through conductivity cells, each utilizing platinized-iridium electrodes, except YSI 3418 which has platinized nickel electrodes. These cells have the following specifications:

| Part No. | cgs Cell Constant | S.I. Cell Constant | Material | Overall Length | Max O.D. | Chamber I.D. | Chamber Depth |
|---------------------------|-------------------|--------------------|-------------|----------------|----------|--------------|---------------|
| Dip Cells | | | | | | | |
| YSI 3401 | K=1.0/cm | K=100/m | Pyrex 7740 | 7 1/2" | 1" | 13/16" | 3" |
| YSI 3402 | K=0.1/cm | K=10/m | Pyrex 7740 | 6 1/4" | 1" | 13/16" | 2 1/16" |
| YSI 3403 | K=1.0/cm | K=100/m | Pyrex 7740 | 7" | 1 1/2" | 3/8" | 2" |
| YSI 3417 | K=1.0/cm | K=100/m | ABS Plastic | 5 3/4" | 1 1/2" | 3/8" | 3/4" |
| YSI 3418 | K=0.1/cm | K=10/m | ABS Plastic | 6 1/4" | 1 1/2" | 3/8" | 1 3/16" |
| YSI 3440 | K=10.0/cm | K=1000/m | Pyrex 7740 | 8" | 1 1/2" | 5/64" | 3 3/8" |
| Flow-Through Cells | | | | | | | |
| YSI 3445 | K=1.0/cm | K=100/m | Pyrex 7740 | 5 3/4" | 3/4" | 3/8" | 3" |
| YSI 3446 | K=0.1/cm | K=10/m | Pyrex 7740 | 5 3/4" | 1" | 13/16" | 3" |

The nominal volumes of the flow-through cells are 15 ml for the YSI 3445 and 30 ml for the YSI 3446.

The cell part number and cell constant (K) are fired onto the Pyrex cells and are stamped on the plastic cells.

Cell constants are calibrated to \pm 1% accuracy against 0.01 normal KCl solution by means of a YSI transfer standard. (See Cell Calibration and Standard Solutions.)

Cell Constant

The cell constant (K) is a factor which is used to determine resistivity or conductivity of a solution. In a geometrical sense this factor is, as its name implies, a true constant. However, the electrical properties of a cell do vary with electrolyte concentration and this variation should be taken into consideration if maximum accuracy is desired. Cell constant is determined by the physical configuration of the cell and its electrodes. Cells with constants of 1.0/cm or greater normally have small, widely-spaced electrodes while cells with constants of 0.1/cm or less have larger electrodes which are closely-spaced.

The user should decide which cell will be more useful based on the conductivities of the solutions in which he will be making measurements. Generally, $K = 1.0/\text{cm}$ cells will give good results with solutions between 20 and 20,000 micromhos. Values below or above this range are best measured with $K = 0.1/\text{cm}$ or $K = 10.0/\text{cm}$ cells. $K = 0.1/\text{cm}$ cells may be used for any value below 2,000 micromhos, and $K = 10.0/\text{cm}$ cells for any value above 2,000 micromhos.

Conductivity is determined by multiplying the conductance measured in mhos or siemens by the appropriate cell constant (K), being careful to observe the dimensions of the constant.

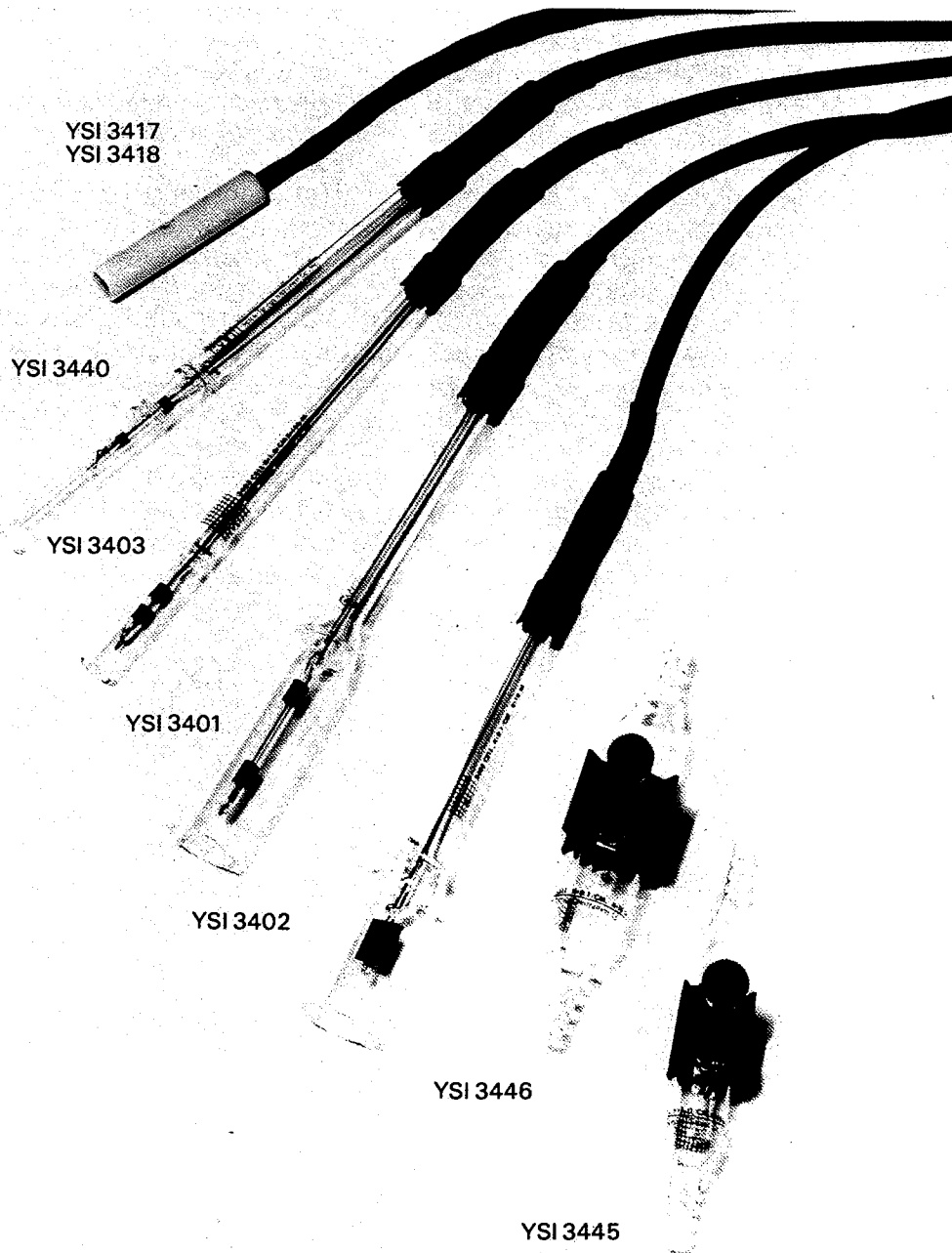


Figure 1: YSI 3400 Series Conductivity Cells

MEASUREMENT PROCEDURE

Instrument

1. Connect the instrument to an appropriate power source.
2. Connect the conductivity cell leads to the terminals marked "CELL."
3. Immerse the conductivity cell into the solution to be measured. The electrodes must be submerged and the electrode chamber must be free of trapped air. Tap the cell to remove any bubbles, and dip it two or three times to assure proper wetting.
4. Rotate the range switch to the lowest range position which results in a reading (within range) on the display.
5. The conductance value of the solution is displayed on the meter. The switch position determines the units displayed: either millimhos or micromhos.
6. Conductivity may now be determined by multiplying the conductance value displayed by the cell constant K. Units are either micromhos/centimeter or millimhos/centimeter when K is dimensioned in centimeters⁻¹. When K is dimensioned in meters⁻¹, the units are either microsiemens/meter or millisiemens/meter. (The rules of S.I. discourage expressions like millisiemens/centimeter.)
7. If a measurement record is desired, the YSI Model 35 may be connected to any recorder or other voltage measuring device with a 10 k Ω or higher input impedance. The terminals present a 0 to 2 volt signal proportional to the meter reading which remains linear to 50% overrange (3 volts). For proper operation, the recorder output terminals must be kept electrically isolated from the cell circuit.

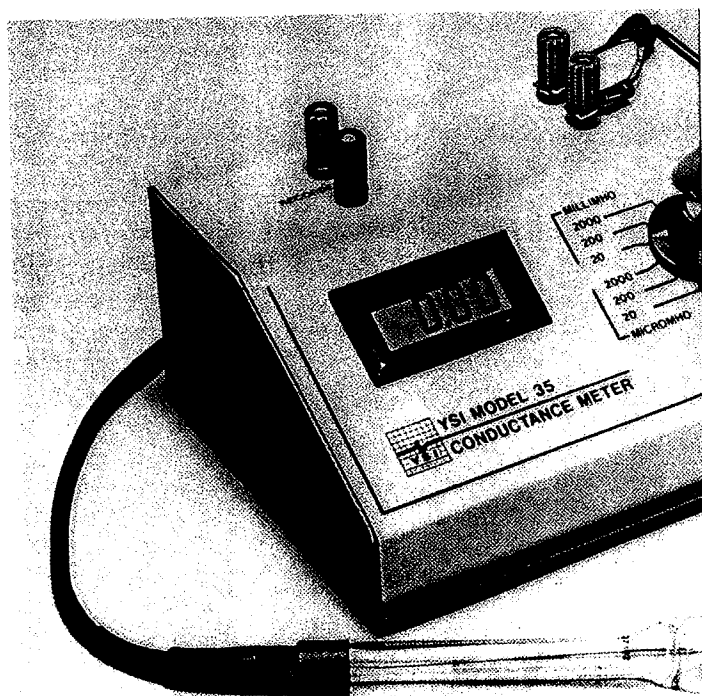


Figure 2: Setting the display range on the Model 32

Cell Precautions

After selecting the proper cell, observe the following precautions in order to assure accurate, repeatable results:

1. The cell must be clean before making any measurement. (When working with substances having low conductivity, extraordinary cleanliness may be required.)
2. The cell should be suspended in the solution in such a way that the vent slots are submerged. The electrode chamber should be free of trapped air. (This may be accomplished by tilting the cell slightly and tapping the side.)
3. The cell should be at least 1/4 inch away from any other object, including the walls or bottom of the solution container.
4. Stirring may be necessary for the highest accuracy in measurement, especially in low-conductivity solutions.
5. If it is possible, the container or system in which measurements are to be made should be isolated from ground potential. If a recording device is attached to the recorder output terminals, it too should be isolated from ground potential if possible. If both cannot be isolated, at least one *must* be to prevent possible ground loop currents which can have an unpredictable error affect.
6. The presence of electrical fields and stray currents caused by stirrer motors, heaters, etc., can cause difficulties in obtaining good measurement results.

The user should determine the effects of these and make the necessary corrections, either by shielding or by disconnecting during measurements those units which cause trouble.

7. The cell should always be handled carefully to decrease the possibility of breakage or loss of calibration accuracy.
8. The cell should never be transferred from one type of solution to another without having first been carefully rinsed.
9. Never store a dirty or contaminated cell.
10. In order to construct an easily calibrated, rugged cell, YSI solders the electrodes and supports in the 3400 Series Cells with gold solder. For this reason, the cells should not be submerged in aqua regia or any solution which might etch or dissolve gold.

The user should determine the effects of these and make the necessary corrections, either by shielding or by disconnecting during measurements those units which cause trouble.

7. The cell should always be handled carefully to decrease the possibility of breakage or loss of calibration accuracy.
8. The cell should never be transferred from one type of solution to another without having first been carefully rinsed.
9. Never store a dirty or contaminated cell.
10. In order to construct an easily calibrated, rugged cell, YSI solders the electrodes and supports in the 3400 Series Cells with gold solder. For this reason, the cells should not be submerged in aqua regia or any solution which might etch or dissolve gold.

Temperature Correction

The conductivity of electrolytic solutions varies with temperature, concentration and composition. The temperature coefficient may have a value as high as 3%/°C and each conductive ion has a different temperature coefficient. The coefficient is non-linear. By convention, the conductivity of a solution is the conductivity it exhibits at 25°C.

For high precision work ($\pm 1\%$), uniform determination of solution conductivity is achieved by performing measurements at $25^\circ\text{C} \pm 0.1^\circ\text{C}$. For routine lab work, $25^\circ\text{C} \pm 0.5^\circ\text{C}$ may be acceptable. (Ref.: ASTM D 1125-64 Standard Methods of Test for Electrical Conductivity of Water.)

When sample temperature control is not practical, temperature correction calculations are employed to estimate conductivity at 25°C. The actual sample temperature coefficient can be determined either from published data or from measurements of representative samples. This coefficient may then be applied to correct future measurements on samples of similar composition. If sample composition changes appreciably, the coefficient should be redetermined.

Once the temperature coefficient is known, the conductivity at 25°C can be determined from:

$$k_{25} = \frac{k_T}{1 + \alpha \Delta T}$$

- where k_{25} = conductivity at 25°C
 k_T = conductivity at measurement temperature T
 α = temperature coefficient of conductivity (change per degree C)
 ΔT = difference between measurement temperature and 25°C (T-25°C).

Determining Temperature Coefficient

Equipment

1. Conductance Meter
2. Conductivity Cell
3. Two 1-liter glass or plastic containers
4. Controlled temperature bath
5. Thermometer
6. One split rubber stopper to seal one of the 1 liter containers, bored to hold the conductivity cell and thermometer.

Procedure

1. Install the cell and thermometer in the stopper so that both will be well submerged when the stopper is in place on the container.
2. Clean the containers, cell, thermometer and stopper in deionized water.
3. Fill both containers with the solution of interest.
4. Rinse the cell and thermometer in one sample, then place the stopper in the second sample, checking that the cell and thermometer are submerged and that no air bubbles are trapped in the cell (see Figure 3).

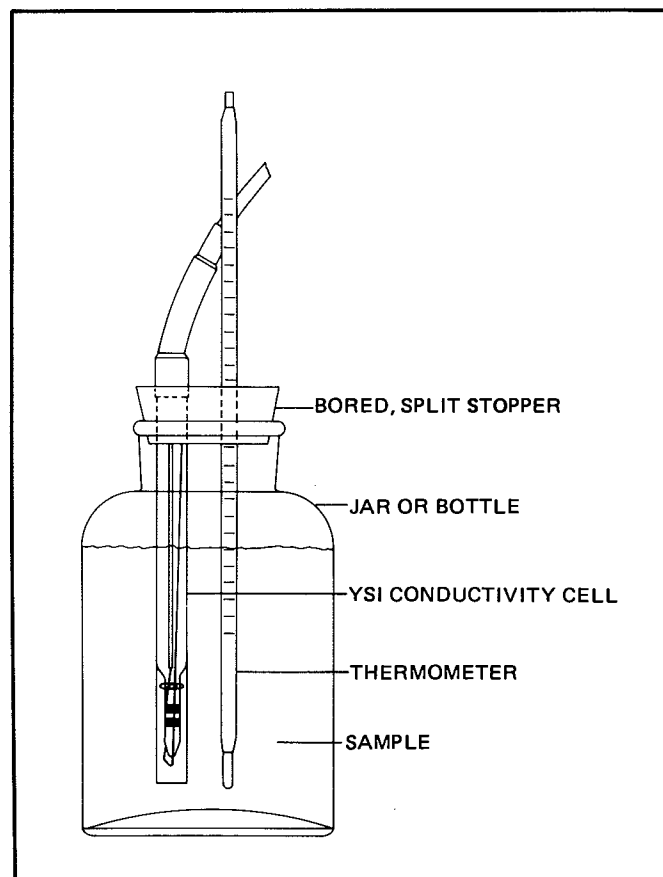


Figure 3. Temperature Coefficient Test Setup, showing a YSI 3403 Conductivity Cell in use.

5. Place the sealed sample in the controlled bath and set the bath control to obtain a reading of 25°C on the sample thermometer. Use gentle swishing to stir the sample and measure the solution conductivity and temperature.
6. Heat the solution to the upper limit of expected sample temperature and measure the conductivity and temperature.
7. Cool the solution to the lower limit of expected sample temperature and measure the conductivity and temperature.
8. Plot the three conductivity/temperature points on graph paper. The three points should be approximately linear. If they are not, the data may contain errors or else the solution may not have a linear temperature coefficient. If there are errors, repeat steps 2-7 on a fresh sample. If the temperature coefficient is not linear, the temperature range of interest can be broken up into segments small enough so that the coefficient for each separate segment is nearly linear.
9. If the solution is linear, compute the temperature coefficient α by the formula:

$$\alpha = \frac{k_T - k_{25}}{k_{25} \times \Delta T}$$

where terms are as defined above.

Small Sample Measurement

It is not always possible to immerse the conductivity cell in a solution for measurements. If the quantity of solution is not accessible to a dip cell, a sample must be removed for assay. For this application, any 3400 Series Cell (except 3418) may be inverted and used as a sample holder.

The selection of a proper cell for small sample applications will depend upon the quantity of solution available and the conductivity of the solution. The

3401 cell (K = 1.0/cm) requires 15 ml, the 3402 cell (K = 0.1/cm) requires 12 ml, the 3403 cell (K = 1.0/cm) requires 3 ml, and the 3417 cell (K = 1.0/cm) requires 1 ml.

In use, the cell's vent slots are sealed and the electrode chamber is filled with solution. Conductance is measured and multiplied by a corrected cell constant. This corrected constant may be determined as outlined in the following steps.

1. Before sealing the vent slots, immerse the cell in room temperature tap water (or, preferably in a standard solution) and measure conductance.
2. Multiply by the cell constant to determine conductivity.
3. Seal the vent slots and fill the electrode chamber with some of the same solution and again measure conductance. Take care to ensure that neither solution temperature nor composition change during these steps.
4. Multiply by the cell constant to determine conductivity.
5. Divide the difference between the two conductivity determinations by the conductivity obtained in Step 4.
6. The result of Step 5 is a percent variation of cell constant. Add this variation to the constant marked on the cell. The result is the cell constant to use whenever the vent slots are closed.

Example: Cell constant (K) = 1.0/cm

Step 1 — Conductance = 1200 micromhos

Step 2 — Conductivity = 1200 x 1.0/cm = 1200 micromhos/cm

Step 3 — Conductance = 1000 micromhos

Step 4 — Conductivity = 1000 x 1.0/cm = 1000 micromhos/cm

Step 5 — (Difference = 200 micromhos/cm) divided by 1000 micromhos/cm = 0.20

Step 6 — 0.20 = 20% of 1.0

Cell Constant (K) with closed slots = 1.20/cm.

MAINTENANCE AND CALIBRATION OF CELLS

Cleaning and Storage

The single most important requirement for accurate and reproducible results in conductivity measurement is a clean cell. A dirty cell will contaminate the solution and cause the conductivity to change.

1. Any one of the foaming acid tile cleaners, such as Dow Chemical "Bathroom Cleaner," will clean the cell adequately. When a stronger cleaning preparation is required, use a solution of 1:1 isopropyl alcohol and 10N HCl.

Caution: Cells should not be cleaned in aqua regia or in any solution known to etch platinum or gold.

2. Dip or fill the cell with the cleaning solution and agitate for two or three minutes.
3. Remove the cell from the solution and rinse it in several changes of distilled or deionized water. Inspect the platinum black to see if replatinizing is required.
4. It is best to store conductivity cells in deionized water. Cells stored in water will require less frequent platinization. Any cell that has been stored dry should be soaked in distilled water for 24 hours before use.

Platinum Black Inspection

The electrodes of YSI 3400 Cells are coated with platinum black before calibration. This coating is extremely important to cell operation, especially in solutions of high conductivity.

The cell should be inspected periodically. If the coating appears to be thin or if it is flaking off, the electrodes should be cleaned as noted above, and replatinized.

Replatinizing

A YSI 3139 Platinizing Kit is available from your dealer. The kit includes three 1.5 volt batteries, a milliammeter, a current control, and a reversing switch. These are mounted in a convenient plastic case. The kit also includes a bottle to hold platinizing solution. A 2-oz bottle of platinizing solution (YSI 3140) may also be obtained from your dealer. Platinizing is accomplished as follows:

1. Place solution in the platinizing bottle. (Dip cells only.)
2. Connect the cell to the binding posts.
3. Place the cell in the solution with both electrodes submerged. For flow-through cells, plug end and fill the cell with solution. Use of tubing and a small funnel will simplify this operation.
4. Adjust the current control for 50mA indication. (For a cell constant of $K = 10.0$, adjust for maximum current possible by the control.)
5. Reverse polarity to the cell every 30 seconds until both electrodes are covered with a thin black

layer. Do not overplatinize.

6. Remove the cell from the solution (or empty the flow-through cell) and disconnect it from the binding posts.
7. Return the platinizing solution to its bottle. It may be reused many times. It is expensive and should not be wasted.
8. Rinse the electrodes in running tap water for about 15 minutes.
9. Rinse the cell in distilled or deionized water and store or use.



Figure 4: The YSI 3139 Platinizing Kit in use.

Cell Calibration and Standard Solutions

YSI 3400 Series Cells are calibrated to an accuracy of $\pm 1\%$ by means of a standard solution. Since the literature does not indicate a consistently accepted standardization approach, we have chosen the approximately 0.01 normal KCl solution method as determined by Jones and Bradshaw in 1937. Recent textbooks, as well as the ASTM standards, concur in this choice.

The solution is prepared by diluting 0.745 grams of pure dry KCl with distilled water until the weight is 1 kilogram. The following table shows the values of conductivity this solution would have if the water were non-conductive. However, since even high purity distilled water is slightly conductive, the measured conductivity will be higher by an amount equal to the contribution of the water.

Temperature vs. Conductivity, 0.01 Normal KCl Solution

| Temperature (°C) | Conductivity (Absolute Micromhos/cm) |
|------------------|---|
| 15 | 1141.5 |
| 16 | 1167.5 |
| 17 | 1193.6 |
| 18 | 1219.9 |
| 19 | 1246.4 |
| 20 | 1273.0 |
| 21 | 1299.7 |
| 22 | 1326.6 |
| 23 | 1353.6 |
| 24 | 1380.8 |
| 25 | 1408.1 |
| 26 | 1435.6 |
| 27 | 1463.2 |
| 28 | 1490.9 |
| 29 | 1518.7 |
| 30 | 1546.7 |

The operator may use the standard solution and the table to check accuracy of the cell's constant or to determine an unknown constant. The formula is

$$K = \frac{k_1 + k_2}{\frac{1}{R}}$$

where K = cell constant in c.g.s. metric units (centimeters⁻¹).

$\frac{1}{R}$ = measured conductance in micromhos
 k_1 = conductivity in absolute micromhos/cm from table above

k_2 = conductivity in absolute micromhos/cm of the distilled water used in making solution.

$\frac{1}{R}$, k_1 , and k_2 must either be determined at the same temperature or corrected to the same temperature to make the equation valid.

Note: For further information on conductivity and on the above standard information, refer to ASTM Standards Part 23—Standard Methods of Test for Electrical Conductivity of Water and Industrial Wastewater—ASTM Designation D1125-64. (ASTM symbols for conductivity, cell constant and path length differ from those preferred in the general literature and also from those used in this instruction manual.)

Standard solutions available from YSI:

| Part Number | Size | Conductivity at 25.00°C |
|-------------|--------|-----------------------------|
| 3160 | Gallon | 1,000 micromho/cm ± 0.25% |
| 3161 | Quart | 1,000 micromho/cm ± 0.25% |
| 3162 | Gallon | 10,000 micromho/cm ± 0.20% |
| 3163 | Quart | 10,000 micromho/cm ± 0.20% |
| 3164 | Gallon | 100,000 micromho/cm ± 0.20% |
| 3165 | Quart | 100,000 micromho/cm ± 0.20% |

APPENDICES

I. Technical Information

Circuit Description

Referring to the schematic diagram of Figure 3, it will be seen that the electronics can be divided into a number of functional blocks (which are, however, not physically modular). These include a square wave modulator (utilizing the active components U1 c&d, U2, Q1 and Q2), a cell driving amplifier (U3, Q3 and Q4), a cell voltage integrator (U4) forming an active feedback loop around the cell driving amplifier, a synchronous demodulator (U1a, U1b and U5) and a differential integrator (U6). In addition there is a reference voltage divider string, the display and, of course, the power supply.

The square-wave modulator circuit consists of one half of U1 plus U2, Q1, Q2 and their associated resistors and diodes up to the switch poles. U1 is a CMOS quad bilateral gate that serves as a fast electronic switch. When the control input of one of its gates is at a high logic level, the corresponding gate is in its low impedance state (switch closed). When the control input is at a low logic level, the gate is in its high impedance state (switch open). The control inputs of U1c and U1d are connected respectively to the clock output and to the complementary clock output. This assures that only one will be in its low impedance state at any given moment while they alternate between open and closed. When U1d is conducting, the modulator circuit acts as a unity gain inverter. When U1c is conducting, the modulator acts as a unity gain follower. Since U1d and U1c conduct alternately, the output of the modulator is a square wave voltage with an amplitude equal to the voltage at the output of U6. The functions of U6 and the differential integrator in which it is found will be taken up later in this discussion.

The range of output current available from the modulator is extended by Q1 and Q2 which in turn are protected from excessive power dissipation by R10 and R11 and by D4, D5, D6 and D7.

The cell driving amplifier converts the square wave voltage from the modulator into a square wave current which it forces through the cell. The scaling factor for this conversion is determined by one of the resistors from R13 to R17 that is switched in for a particular range. Q3 and Q4 extend the current capabilities of U3; current limiting similar to that of the modulator circuit is employed.

A long time-constant integrator, U4, R20, and C4, is used to monitor the DC voltage at J4 with respect to circuit common. The voltage at the output of U4 decreases when J4 is at a potential higher than circuit common, and increases when J4's po-

tential is lower than circuit common. When the average voltage over one complete clock cycle at J4 is equal to zero, the average output of U4 remains constant.

The output of U4 is connected to the non-inverting input of U3 to form an active feedback loop around the cell driving amplifier. This active feedback removes the offset errors introduced by U2 and U3, and also forces the DC voltage at J4 to zero.

The demodulator, composed of U1a, U1b, U5, R21 and R22, is synchronized with the modulator to switch between a unity gain follower and inverter. The demodulator is 180° out of phase with the modulator to correct for the 180° phase shift in the cell driver. The output of the demodulator is connected to the inverting input of the differential integrator.

Resistors R24 through R28, C9 and U6 form a differential integrator circuit that serves two purposes. First, it compares the output of U5 with a reference voltage from the divider string between test point 3 (TP3) and circuit common. The voltage at the output of U6 decreases when the output of U5 is higher than the reference and increases when U5's output is lower than the reference. Its second purpose is to keep the higher components of U5's output voltage from the meter, the recorder output, and the modulator circuit. The output of the differential integrator feeds the square-wave modulator, completing the major feedback loop.

The circuit reaches a state of equilibrium when the average demodulator output equals the reference voltage, causing the differential integrator (U6) output voltage to remain constant. To understand how a conductance at the cell terminals is determined, it is easiest to work back through the loop from this condition of equilibrium. For the average demodulator output to be equal to the reference voltage, the average absolute value of the cell driver output must be equal to the reference voltage. The gain of the cell driver amplifier is equal to the reciprocal of the product of the cell conductance times the resistance in ohms of the scaling resistor (R13 to R17).

$$A = \frac{1}{\frac{1}{R_s} \times R'} = \left(\frac{R'}{R_s}\right)^{-1} = \frac{R_s}{R'}$$

where $\frac{1}{R_s}$ = cell conductance
 R' = scaling resistance

The input voltage to the cell driving amplifier is its output voltage divided by its gain:

$$V_{in} = \frac{V_o}{A}$$

The output voltage is equal to the reference voltage

$$V_o = V_{REF}$$

So the input voltage of the cell driving amplifier can be expressed as

$$V_{in} = V_{ref} \times \frac{R'}{R_s} = V_{REF} \times R' \times \frac{1}{R_s}$$

The cell driving amplifier input is connected to the square wave modulator output. It was shown earlier that the amplitude of the voltage at the modulator output is equal to the voltage of U6, which is the voltage represented at the recorder output terminals. This voltage is proportional to the conductance at the cell terminals in accordance with the relationship given above. The reference voltage and scaling resistor values are switched to give 2 volts full scale on all ranges at the recorder output.

Complementary clock signals are generated by U7. The output frequency is determined by the RC network formed by R46 and C10. The clock frequency is increased for the high conductance ranges by switching R47, R48, or R49 in parallel with R46. A 50% duty cycle is guaranteed by an on-chip frequency divider.

Power for the Model 35 is 115 VAC. A line fuse is located on the back of the instrument, and the power switch is on the range selector. Transformer T1 steps down the line voltage. Its secondary is connected to bridge rectifier D1 for full wave rectification. The rectified sine wave is filtered by C2 before going to a three terminal 15 volt regulator, U8. Circuit common is set 7 volts below the positive supply by a zener diode, D3. This zener-regulated voltage is used by the long divider string to establish all of the circuit reference voltages.

The liquid crystal display module performs the analog-to-digital conversion and the display driver functions. The difference in voltage between the RFL and RFH pins sets the conversion scale factor for the meter. When the voltage between INHI and INLO equals the voltage between RFH and RFL the meter will read 1000.

Calibration

The instrument was fully calibrated and tested at the factory before shipment. If components are replaced, or if the instrument has been in service for a long time, a calibration check may be desirable. The YSI Service Department can provide prompt calibration assistance or the procedure outlined below may be followed. A set of precision resistors mounted on double banana jacks that plug directly into the cell terminals is also available from the factory for checking instrument calibration (YSI 3166 Conductance Calibrator Set).

Equipment Required

1. DVM—at least 4½ digit; ±0.01% accuracy between 1 and 2 volts
2. Non-inductive Resistance Decade Box ±0.02%

Procedure

1. Turn the instrument on. Ambient temperature should be between 20 and 25°C. Allow the instrument temperature to stabilize.
2. Connect the DVM to recorder output terminals. Connect the resistance decade box to cell terminals. The internal resistance of the decade box and the resistance of the connecting leads should be added to the decade box setting for accurate calibration.
3. Set the resistance to 5.05 k Ω, ±0.02% and switch the instrument to its 200.0 micromho range.
4. Adjust R34 for a reading on the DVM of 1.9800 V ±0.3 mV.
5. Adjust R5 for a reading on the Model 35 of 198.0
6. Set the resistance to 50.5 k Ω, ±0.02%, switch to the 20 micromho range, and adjust R31 for a reading on the DVM of 1.9800 V ±0.3 mV.
7. Set the resistance to 505 Ω, ±0.02%, switch to the 2000 micromho range, and adjust R36 for a reading on the DVM of 1.9800 V ± 0.03mV.
8. Set the resistance to 50.5 Ω ± 0.02%, switch to the 20 millimho range, and adjust R38 for a reading on the DVM of 1.9800 V ±0.03 mV.
9. Set the resistance to 5.05 Ω ±0.02%, switch to the 200 millimho range, and adjust R41 for a reading on the DVM of 1.9800 V ±0.3 mV.
10. Set the resistance to 0.505 Ω ±0.10%, switch to the 2000 millimho range, and adjust R44 for a reading on the DVM of 1.98000 V ±0.5 mV.

Troubleshooting and Repair

If you experience difficulty with any YSI product, it may be returned to an authorized YSI dealer for repair even if the warranty has expired. If you need factory assistance for any reason, contact:

Service Department
 Yellow Springs Instrument Co., Inc.
 P. O. Box 279
 Yellow Springs, Ohio 45387, U.S.A.
 Phone (513) 767-7241

The following service information is provided for those users who have repair facilities and prefer to maintain their own equipment.

When a problem is encountered, the instrument and cell should first be inspected to eliminate the possibility of improper settings or faulty connections. Disconnect all external leads (including recorder output) except power, then substitute an appropriate resistance value for the cell (see below). The YSI 3166 Conductance Calibrator Set provides convenient resistor packages designed for this purpose.

Cell Resistance for 1000 Count Display

| Range | Resistance | Display |
|---------------|------------------|---------|
| 20 micromho | 100.00k Ω | 10.00 |
| 200 micromho | 10.00k Ω | 10.00 |
| 2000 micromho | 1.00k Ω | 10.00 |
| 20 millimho | 100.00 Ω | 10.00 |
| 200 millimho | 10.00 Ω | 10.00 |
| 2000 millimho | 1.00 Ω | 10.00 |

Verify each of the readings shown in the table. If these are obtained, the instrument may be placed back in service. If not, proceed as outlined below.

Before attempting to isolate an apparent fault, inspect the printed-circuit board and wiring for evidence of damage or overheating.

Begin the fault isolation procedure by selecting the symptom from the "Fault Definition" list below which best describes the malfunction, and then proceed to the troubleshooting table indicated. Follow the checks in the troubleshooting table, using the circuit description, schematic, and assembly drawing as guides. When the conditions in the check statement are not met, perform the corrective procedure or troubleshoot the components specified. Observe standard electrical safety precautions when operating this or any other electrical device with the protective cover removed.

Fault Definition

Symptom

Troubleshooting Table

| | |
|---|---|
| No indication of power | 1 |
| Recorder output OK, display malfunction | 2 |
| Display locked up in overrange | 3 |

TROUBLESHOOTING TABLES

Table 1 Power Supply

Symptom: No indication of power; blank display, no recorder output voltage.

Check

1. Ensure that line voltage matches instrument rating. Check fuse.
2. Check for normal operation.
3. Check for 17 to 34 volts unregulated DC across C2.
4. Check for 15 volts regulated DC from TP4 to TP3

Troubleshoot

Replace fuse
 D1, C2, C3, U8 and T1
 Power switch, T1, D1 and C2
 U8, C3, excessive loading

Table 2 Display

Symptom: Recorder output OK, display malfunctioning.

Check

1. Check for 13 to 14.5 VDC between V_{SS} and V_{DD} on the display board.
 2. Check for 95 mV DC between RFH on the display board and circuit common (TP1).
 3. Check for 0 VDC between RFL, INLO and COM on the display board.
 4. Check for 0 VDC between TP6 and INHI on the display board.
 5. *Momentarily* place jumper from TP6 to TP1, and verify that the display reads zero.
 6. *Momentarily* place a jumper from TST on the display board to TP3 and verify that all segments are visible.
- CAUTION: Damage to the LCD may occur if left in this mode for several minutes.

Troubleshoot

Flat cable, D2, power supply
Flat cable, R5

Flat cable
Flat cable
Display board

Display board

Table 3 Control Loop

Symptom: Display locked up in overrange.

Check

1. Check for 7 V regulated DC between TP1 and TP3.
2. Check for 1.3 to 1.6 VDC across D2.
3. Check for 95 mV DC between RFH on the display board and circuit common (TP1).
4. Momentarily place a jumper from TP6 to TP1. Verify that the display reads zero.
5. Check for a 50% duty cycle squarewave voltage of + and -7 volts with respect to circuit common (TP1) at both TP7 and TP8.
6. Check for a squarewave voltage between the common node of resistors R10 and R11, and circuit common (TP1), with peak-to-peak voltage equal to twice the recorder output voltage.
7. Is the DC component of the voltage at cell terminal J4 less than 20 mV with respect to circuit common?
8. Is the output voltage of U5 (pin 6) higher than the voltage at pin 3 of U6 for negative overrange or is the output voltage of U5 (pin 6) lower than the voltage at pin 3 of U6 for positive overrange?
9. Is the average DC output voltage of U5 (pin 6) equal to one-half the peak-to-peak squarewave voltage at cell terminal J4?
10. Check U3, U4, C4, Q3, Q4, and D8 through D11.

Troubleshoot

D3, go to Table 1
D2, flat cable
Flat cable, R5, U6

Flat cable, go to Table 2

U7, C10, U1

U1, U2, D4 through D7

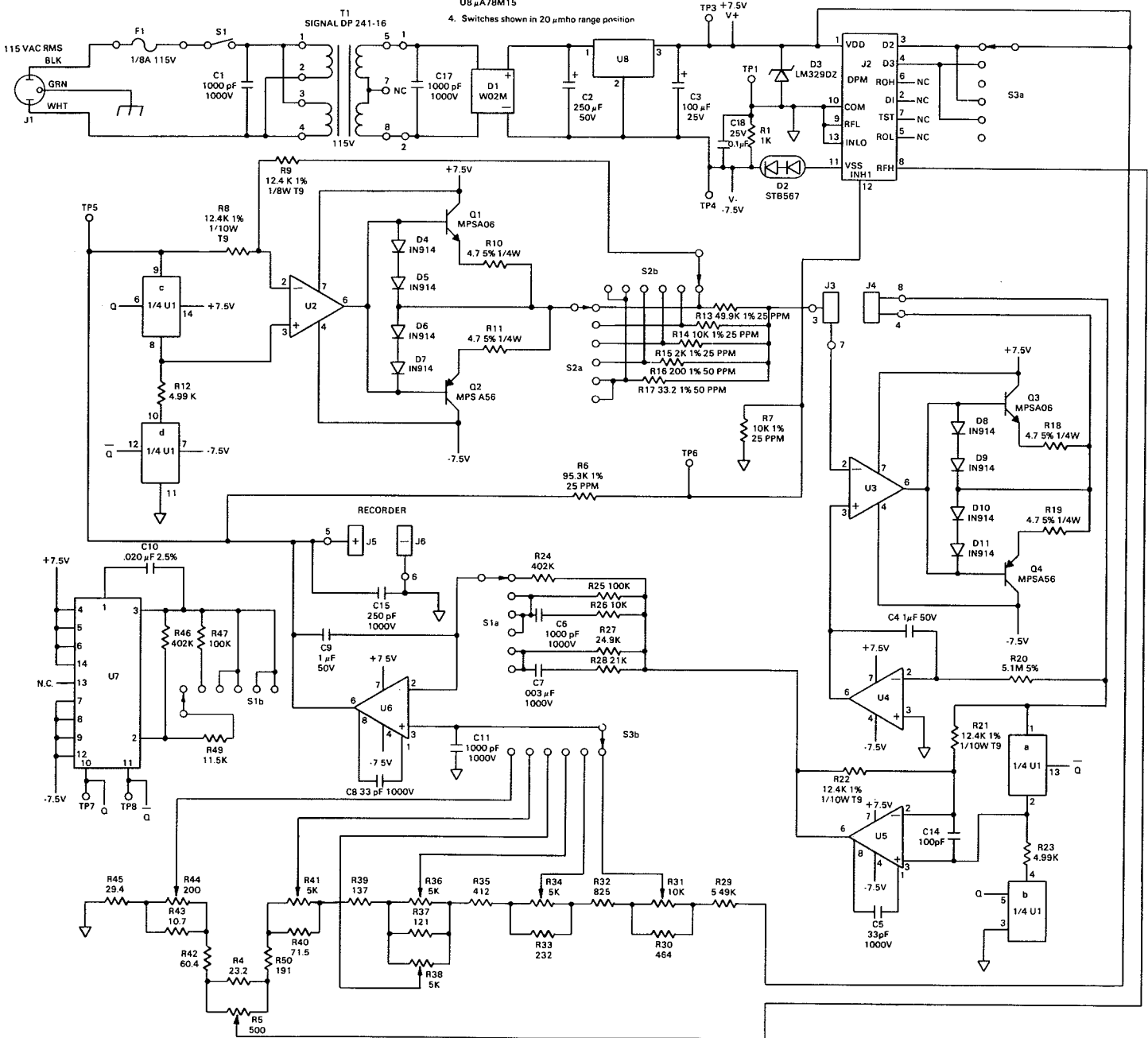
U4, C4, U3, Q3, Q4, D8 through D11
U6, C9, wafer switch

U1, U5, C14

Service Parts

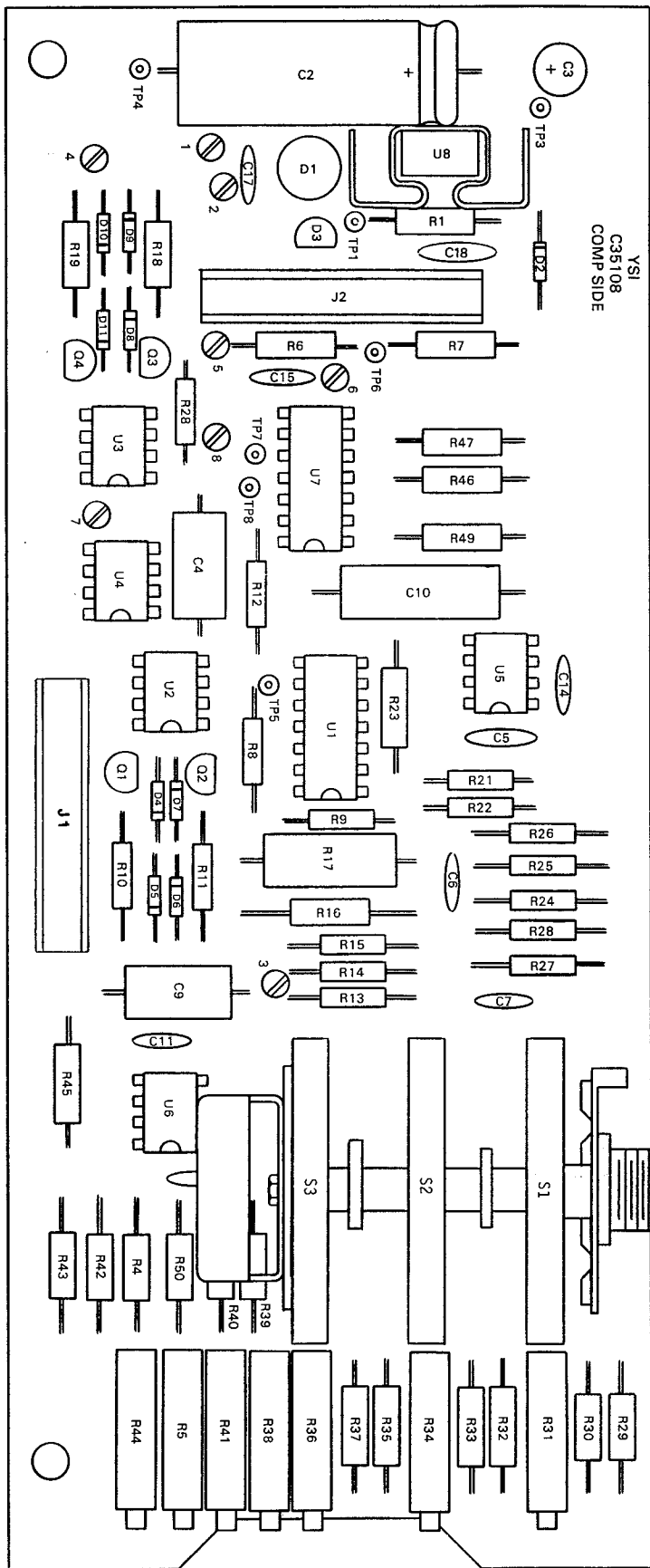
| Component | Description | YSI Item No. | Component | Description | YSI Item No. |
|---------------|-----------------------|--------------|-----------|---|--------------|
| | PC BOARD ASSEMBLY | 069763 | J2 | FLAT CABLE, 13 COND, WITH POLARIZED HOUSING | 069744 |
| C2 | CAP, ELE, 250MF, 50V | 015584 | | | |
| C3 | CAP, ELE, 100MF, 25V | 078530 | | | |
| D1 | DIODE BRIDGE 200PIV | 025880 | J3 J4 | BINDING POST, BLUE | 028114 |
| D2 | STABISTOR STB567 | 026136 | J5 | BINDING POST, RED | 016816 |
| D3 | ZENER LM329DZ 6.9V | 026313 | J6 | BINDING POST, BLACK | 016728 |
| D4 D5 D6 D7 | DIODE 1N914 | 078165 | | SWITCH ASSEMBLY | 069783 |
| D8 D9 D10 D11 | | | | KNOB | 028108 |
| U1 | IC MC14066BCP | 025969 | | BEZEL | 069481 |
| U2 U3 U4 | IC AMP 081 JFET INPUT | 028077 | | DISPLAY BOARD ASSEMBLY | 069487 |
| U5 U6 | IC AMP 308A LM308AN | 012257 | | | |
| U7 | IC CD4047BE | 025970 | | TRANSFORMER | 069767 |
| U8 | REGULATOR UA78M15C | 069771 | | FUSE, 1/8 A (115V) | 019649 |
| Q1 Q3 | TRSTR NPN MPSA06 | 027024 | | FUSE, 1/16 A (230V) | 019698 |
| Q2 Q4 | TRSTR PNP MPSA56 | 027025 | | | |

- GENERAL NOTES:
1. ALL RESISTORS, EXPRESSED IN OHMS, ARE 1/4W 1% T1, UNLESS OTHERWISE SPECIFIED.
 2. ALL POTENTIOMETERS ARE 20 TURN CERMET
 3. IC IDENTIFICATION
 U1 CD4066BCN
 U2 CA81AE
 U3 CA81AE
 U4 CA81AE
 U5 LM308AN
 U6 LM308AN
 U7 CD4047B
 U8 μ A78M15
 4. Switches shown in 20 μ mho range position



This schematic is representative only, and may be slightly different from the circuit in your instrument.

Model 35 Schematic Diagram



This schematic is representative only, and may be slightly different from the circuit in your instrument.

Model 35 Component Layout

II. Temperature Correction Data For Typical Solutions

A. Sodium Chloride* (NaCl)

| Saturated solutions at all temps. | | | Concentration: 0.5 mole/liter | | |
|-----------------------------------|--------------|----------------|-------------------------------|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 134.50 | 1.86 | 0 | 25.90 | 1.78 |
| 5 | 155.55 | 1.91 | 5 | 29.64 | 1.82 |
| 10 | 177.90 | 1.95 | 10 | 33.61 | 1.86 |
| 15 | 201.40 | 1.99 | 15 | 37.79 | 1.90 |
| 20 | 225.92 | 2.02 | 20 | 42.14 | 1.93 |
| 25 | 251.30 | 2.05 | 25 | 46.65 | 1.96 |
| 30 | 277.40 | 2.08 | 30 | 51.28 | 1.99 |
| | | | 35 | 56.01 | 2.01 |
| | | | 37.5 | 58.40 | 2.02 |
| | | | 40 | 60.81 | 2.02 |
| | | | 45 | 65.65 | 2.04 |
| | | | 50 | 70.50 | 2.05 |

| Concentration: 1 x 10 ⁻¹ mole/liter | | | Concentration: 1 x 10 ⁻² mole/liter | | |
|--|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 5.77 | 1.83 | 0 | .632 | 1.87 |
| 5 | 6.65 | 1.88 | 5 | .731 | 1.92 |
| 10 | 7.58 | 1.92 | 10 | .836 | 1.97 |
| 15 | 8.57 | 1.96 | 15 | .948 | 2.01 |
| 20 | 9.60 | 1.99 | 20 | 1.064 | 2.05 |
| 25 | 10.66 | 2.02 | 25 | 1.186 | 2.09 |
| 30 | 11.75 | 2.04 | 30 | 1.312 | 2.12 |
| 35 | 12.86 | 2.06 | 35 | 1.442 | 2.16 |
| 37.5 | 13.42 | 2.07 | 37.5 | 1.508 | 2.17 |
| 40 | 13.99 | 2.08 | 40 | 1.575 | 2.19 |
| 45 | 15.14 | 2.10 | 45 | 1.711 | 2.21 |
| 50 | 16.30 | 2.12 | 50 | 1.850 | 2.24 |

| Concentration: 1 x 10 ⁻³ mole/liter | | |
|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) |
| 0 | .066 | 1.88 |
| 5 | .076 | 1.93 |
| 10 | .087 | 1.98 |
| 15 | .099 | 2.02 |
| 20 | .111 | 2.07 |
| 25 | .124 | 2.11 |
| 30 | .137 | 2.15 |
| 35 | .151 | 2.19 |
| 37.5 | .158 | 2.20 |
| 40 | .165 | 2.22 |
| 45 | .180 | 2.25 |
| 50 | .195 | 2.29 |

C. Lithium Chloride* (LiCl)

| Concentration: 1 mole/liter | | | Concentration: 1 x 10 ⁻¹ mole/liter | | |
|-----------------------------|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 39.85 | 1.82 | 0 | .507 | 1.87 |
| 5 | 46.01 | 1.85 | 5 | .588 | 1.85 |
| 10 | 52.42 | 1.89 | 10 | .687 | 1.85 |
| 15 | 59.07 | 1.92 | 15 | .775 | 1.85 |
| 20 | 65.97 | 1.95 | 20 | .862 | 1.85 |
| 25 | 73.10 | 1.98 | 25 | .950 | 1.86 |
| 30 | 80.47 | 2.02 | 30 | 10.40 | 1.88 |
| 35 | 88.08 | 2.05 | 35 | 11.31 | 1.91 |
| 37.5 | 91.97 | 2.07 | 37.5 | 11.78 | 1.92 |
| 40 | 95.92 | 2.08 | 40 | 12.26 | 1.94 |
| 45 | 103.99 | 2.11 | 45 | 13.26 | 1.98 |
| 50 | 112.30 | 2.15 | 50 | 14.30 | 2.02 |

| Concentration: 1 x 10 ⁻² mole/liter | | | Concentration: 1 x 10 ⁻³ mole/liter | | |
|--|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | .567 | 1.88 | 0 | .059 | 1.93 |
| 5 | .659 | 1.92 | 5 | .068 | 2.03 |
| 10 | .755 | 1.96 | 10 | .078 | 2.12 |
| 15 | .856 | 2.00 | 15 | .089 | 2.19 |
| 20 | .961 | 2.04 | 20 | .101 | 2.25 |
| 25 | 1.070 | 2.08 | 25 | .114 | 2.28 |
| 30 | 1.183 | 2.12 | 30 | .127 | 2.31 |
| 35 | 1.301 | 2.16 | 35 | .140 | 2.32 |
| 37.5 | 1.362 | 2.18 | 37.5 | .147 | 2.32 |
| 40 | 1.423 | 2.20 | 40 | .154 | 2.31 |
| 45 | 1.549 | 2.24 | 45 | .166 | 2.29 |
| 50 | 1.680 | 2.28 | 50 | .178 | 2.25 |

D. Potassium Nitrate** (KNO₃)

| Concentration: 1 x 10 ⁻¹ mole/liter | | | Concentration: 1 x 10 ⁻² mole/liter | | |
|--|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 6.68 | 1.78 | 0 | .756 | 1.77 |
| 5 | 7.71 | 1.79 | 5 | .868 | 1.80 |
| 10 | 8.75 | 1.81 | 10 | .984 | 1.83 |
| 15 | 9.81 | 1.83 | 15 | 1.105 | 1.86 |
| 20 | 10.90 | 1.85 | 20 | 1.229 | 1.88 |
| 25 | 12.01 | 1.87 | 25 | 1.357 | 1.90 |
| 30 | 13.15 | 1.90 | 30 | 1.488 | 1.93 |
| 35 | 14.32 | 1.92 | 35 | 1.622 | 1.95 |
| 37.5 | 14.92 | 1.94 | 37.5 | 1.690 | 1.96 |
| 40 | 15.52 | 1.95 | 40 | 1.759 | 1.97 |
| 45 | 16.75 | 1.97 | 45 | 1.898 | 1.99 |
| 50 | 18.00 | 2.00 | 50 | 2.040 | 2.01 |

B. Potassium Chloride** (KCl)

| Concentration: 1 mole/liter | | | Concentration: 1 x 10 ⁻¹ mole/liter | | |
|-----------------------------|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 65.10 | 1.67 | 0 | 7.13 | 1.78 |
| 5 | 73.89 | 1.70 | 5 | 8.22 | 1.80 |
| 10 | 82.97 | 1.72 | 10 | 9.34 | 1.83 |
| 15 | 92.33 | 1.75 | 15 | 10.48 | 1.85 |
| 20 | 101.97 | 1.77 | 20 | 11.65 | 1.88 |
| 25 | 111.90 | 1.80 | 25 | 12.86 | 1.90 |
| | | | 30 | 14.10 | 1.93 |
| | | | 35 | 15.38 | 1.96 |
| | | | 37.5 | 16.04 | 1.98 |
| | | | 40 | 16.70 | 1.99 |
| | | | 45 | 18.05 | 2.02 |
| | | | 50 | 19.43 | 2.04 |

| Concentration: 1 x 10 ⁻² mole/liter | | | Concentration: 1 x 10 ⁻³ mole/liter | | |
|--|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | .773 | 1.81 | 0 | .080 | 1.84 |
| 5 | .892 | 1.84 | 5 | .092 | 1.88 |
| 10 | 1.015 | 1.87 | 10 | .105 | 1.92 |
| 15 | 1.143 | 1.90 | 15 | .119 | 1.96 |
| 20 | 1.275 | 1.93 | 20 | .133 | 1.99 |
| 25 | 1.412 | 1.96 | 25 | .147 | 2.02 |
| 30 | 1.553 | 1.99 | 30 | .162 | 2.05 |
| 35 | 1.697 | 2.02 | 35 | .178 | 2.07 |
| 37.5 | 1.771 | 2.03 | 37.5 | .186 | 2.08 |
| 40 | 1.845 | 2.05 | 40 | .194 | 2.09 |
| 45 | 1.997 | 2.07 | 45 | .210 | 2.11 |
| 50 | 2.151 | 2.09 | 50 | .226 | 2.13 |

E. Ammonium Chloride* (NH₄Cl)

| Concentration: 1 mole/liter | | | Concentration: 1 x 10 ⁻¹ mole/liter | | |
|-----------------------------|--------------|----------------|--|--------------|----------------|
| °C | millimhos/cm | %/°C (to 25°C) | °C | millimhos/cm | %/°C (to 25°C) |
| 0 | 64.10 | 1.60 | 0 | 6.96 | 1.82 |
| 5 | 74.36 | 1.53 | 5 | 7.98 | 1.88 |
| 10 | 83.77 | 1.45 | 10 | 9.09 | 1.93 |
| 15 | 92.35 | 1.37 | 15 | 10.27 | 1.97 |
| 20 | 100.10 | 1.29 | 20 | 11.50 | 2.00 |
| 25 | 107.00 | 1.21 | 25 | 12.78 | 2.03 |
| | | | 30 | 14.09 | 2.06 |
| | | | 35 | 15.43 | 2.07 |
| | | | 37.5 | 16.10 | 2.08 |
| | | | 40 | 16.78 | 2.08 |
| | | | 45 | 18.12 | 2.09 |
| | | | 50 | 19.450 | 2.09 |

*Charts developed by computer interpolation of data from CRC Handbook of Chemistry and Physics, 42nd Ed., p. 2606, The Chemical Rubber Company, Cleveland.

**Charts developed by computer interpolation of data from International Critical Tables, Vol. VI, pp. 229-253. McGraw Hill, N.Y.

III. CONDUCTIVITY SYSTEM ACCURACY CONSIDERATIONS

System accuracy, for conductivity determinations, is the sum of the errors contributed by the environment and the various components of the measurement setup. Included are:

- Instrument accuracy
- Cell-constant error
- Solution temperature offset
- Cell contamination (including air bubbles)
- Cell platinization problems
- Electrical noise
- Contact resistance
- Cable series resistance and shunt capacitances
- Cell series and shunt capacitances
- Galvanic effects and miscellaneous

Only the first three of these need be of major concern for typical measurements, although the user should also be careful to see that cells are clean and maintained in good condition at all times. Additional discussion of these and other factors affecting system accuracy is provided below.

Instrument Accuracy

Instrument error, worst case for this purpose, is the stated accuracy for the range being used. It should be noted that many instruments have different specifications for different ranges and that claims are sometimes misleading. For example, the YSI Models 31 and 31A have dial ranges which are greater than the effective measurement range for which an accuracy statement can be provided.

Cell-Constant Error

Some manufacturers provide cells to only a nominal cell-constant value (± 10 to 20%). It is then the user's responsibility to determine the actual cell constant for the range of concentration values in which the cell is to be used. Although YSI does much better than this (see below) there is really nothing wrong with the practice described. Conductivity is found by multiplying a measured conductance value by the cell constant so if the constant is found to be, for example, 1.07/cm rather than 1.00/cm it can be used with equal accuracy, if somewhat less convenience. Conductivity authorities also consider the cell constant to be a non-linear construct and ASTM specifies different cells for different concentration ranges.

YSI cells are calibrated to within one percent of the stated cell constant at a single point and we consider these products to be usefully linear over most instrument ranges. We do, however, also recommend that $K = 0.1/\text{cm}$ cells be used in measuring very low conductivity solutions and that $K = 10.0/\text{cm}$ cells be used in measuring very high conductivity solutions. The cell constant can

be calibrated to $\pm 0.35\%$ accuracy with YSI 3160-3165 Calibrator Solutions.

Temperature Error

The solution temperature error is the product of the temperature coefficient and the temperature offset from 25°C, expressed as a percentage of the reading which would have been obtained at 25°C. The error is not necessarily a linear function of temperature.

Automatic temperature compensation cannot totally eliminate this error but YSI instruments which offer this feature will limit it to 1% of full scale on the range being used, if the proper coefficient is dialed in.

Temperature measurement error is a problem for either automatic compensation or manual temperature correction.

Total Error

Considering only the above three factors, system accuracy under worst case conditions will be $\pm 3\%$, but considerably less if recommended and properly calibrated cells, instrument ranges and automatic temperature compensation are used. Additional errors, which can essentially be eliminated with proper handling, are described below.

Cell Contamination

This error source might usually be more properly described as one in which the cell is contaminating the solution being measured, often through carry-over from previous measurements. The instrument might be correctly reporting the conductivity seen but that reading does not accurately represent the value of the bulk solution. Errors will be most serious when measuring low conductivity solutions and can then be of an order of magnitude or more.

The user should carefully follow the cleaning instructions provided before attempting low conductivity measurements with a cell of unknown history or one which has been previously used in higher value solutions.

An entirely different form of contamination is sometimes seen as a buildup of foreign material directly on cell electrodes. While perhaps rare, examples have turned up where such deposits have markedly reduced the effectiveness of platinization, which in turn reduces the so-called double-layer capacitance and the electrical coupling to the solution being measured. The result is a lower conductance reading (see Cell Platinization Errors below).

Cell Platinization Errors

Most YSI instruments are quite forgiving of a cell

which has begun to lose its electrode coating of platinum black. However significant errors can be introduced when measuring solutions having high conductivity values. The effect of poor platinization is a reduction of the apparent double-layer or series capacitance in the cell, which in turn appears as a frequency-dependent reactance which is difficult to balance in bridge instruments or to cancel completely with bi-polar drive approaches.

Instructions for electrode inspection and replatinization when necessary should be carefully followed before attempting critical measurements of any kind.

Electrical-Noise Errors

Electrical noise can be a problem in any measurement range, but will contribute the most error and be the most difficult to eliminate for the lowest conductance settings. The noise may be either line-conducted or radiated or both and therefore may require revised lead dress, grounding, shielding, or all three. Often all that is necessary is to make sure that parallel leads are of equal length and twisted together and that line-powered instruments are properly grounded. Additional tips on electrical interference reduction will be found in most conductance instruction manuals.

Contact Resistance

It is perhaps only common sense to suggest that a good contact be made between cell leads and instrument terminals, but the magnitude of error that can result from a fraction of an ohm of contact resistance on the highest conductivity range is not always appreciated. Lugs should be clean and free of mechanical distortion. They should fit squarely on terminal posts which should be properly tightened. Leads should also be inspected to verify that no physical damage has occurred which might degrade electrical contact.

Cable Series Resistance and Shunt Capacitance

The short cables provided as a part of regular cell assemblies will introduce negligible error for most measurements. However, if longer cables are required or if extraordinary accuracy is necessary, special precautions and/or cable calibration may be prudent.

When working with solutions having very high conductivity values (more than 200 millimhos/cm), a cable resistance of a tenth of an ohm will introduce an error of 2% or more.

When working with solutions having very low conductivity values (less than 2 micromhos/cm) a cable capacitance of only 100 picofarads will produce errors of 0.3% or more on some instruments. Modern YSI forced-current models can accommodate shunt capacitance ten times

greater than this, down to 1 micromho/cm conductivity, with no significant capacitance error. However caution is still advised when working on our lowest conductivity ranges with ultra-pure waters, etc.

Cell Series and Shunt Capacitances

Most commercial cells intended for laboratory use have negligible shunt capacitance, a few tens of picofarads at most. The capacitance between leads of long cables will generally be of much greater concern (see above). However, special cells having very low constants are sometimes constructed for experimental or industrial applications. For example, process-stream cells having constants of $K = 0.001/\text{cm}$ are known, if not common. Such cells use many interleaved closely-spaced plates of relatively large surface area and therefore exhibit relatively large shunt capacitances.

Although it may be possible to "balance out" even such large shunt reactance effects, a better approach will be to calibrate the measurement for the particular concentration range of interest. Since these unusual cells are placed in service because of special conditions, it can be assumed that the nature of those conditions is understood well enough to also permit special in-situ calibration procedures.

We have already touched upon the series or "double-layer" capacitance effect in the discussion of platinization. It is desirable that this capacitance be as large as possible and platinization helps to achieve this. Indeed, for most measurements series capacitance is so large that its effects can be ignored. The value of this capacitance is not a constant, it varies with solution concentration among other things, but for a properly platinized commercial cell the value is reported to be in the hundreds or even thousands of microfarads. However, not all cells are equal and instruments differ in their abilities to accommodate lower values of capacitance without error.

For some work, cells with very high constants are desirable ($K = 100/\text{cm}$ or above) and such cells are occasionally constructed as needed, sometimes of little more than a pair of parallel wires. In this case, the series capacitance will be too low for any range of accuracy. However, the practice is quite acceptable if special calibration procedures are used and the user recognizes that his equipment will now have very poor linearity.

Galvanic and Miscellaneous Effects

In addition to the error sources described above, there is yet another class of contributors that can be ignored for all but the most meticulous of laboratory measurements. Such errors are always

small and are generally completely masked by the error budget for cell-constant calibration, instrument accuracy, etc. However, they do exist. Examples range from parasitic reactances associated with the solution container and its proximity to external objects to the minor galvanic effects resulting from oxide formation or deposition on electrodes. Only trial and error in the actual measurement environment can be suggested as an approach to reduce such errors.

If the reading does not change as the setup is "tweaked," errors due to such factors can be considered too small to see (lead reversal is one example of adjustments which might be tried).

Required Notice:

(The Federal Communications Commission defines this product as a *Computing Device* and requires the following notice):

This equipment generates and uses radio frequency energy and if not installed and used properly, that is, in strict accordance with the manufacturer's instructions, may cause interference to radio and television reception. It has been type tested and found to comply with the limits for a Class B computing device in accordance with the specifications in Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference in a residential installation. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause interference to radio or television reception, which can be determined by turning the equipment off and on,

IV. Warranty

All YSI products are warranted for one year against defects in workmanship and materials when used for their intended purpose and maintained according to manufacturer's instructions. Damages from accidents, misuse, tampering, or failure to perform prescribed maintenance are not covered. This warranty is limited to repair or replacement at no charge.

If Service Is Required

Contact the dealer from whom you bought the instrument.

Report the date of purchase, model, serial number, and the nature of the failure. If the repair is not covered by the warranty, you will be notified of the charge for repair or replacement.

When shipping any instrument, be sure it is properly packaged for complete protection.

the user is encouraged to try to correct the interference by one or more of the following measures:

- reorient the receiving antenna
- relocate the computer with respect to the receiver
- move the computer away from the receiver
- plug the computer into a different outlet so that computer and receiver are on different branch circuits

If necessary, the user should consult the dealer or an experienced radio/television technician for additional suggestions. The user may find the following booklet prepared by the Federal Communications Commission helpful: "*How to Identify and Resolve Radio-TV Interference Problems.*" This booklet is available from the U.S. Government Printing Office, Washington, DC 20402, Stock No. 004-000-00345-4.



YSI Incorporated

Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio 45387 USA
Phone 513 767-7241 • 800 343-HELP • Fax 513 767-9353 • Telex 205437